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RESEARCH TRENDS

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BUILDINGS SUPPORTED by AIR!

by WALTER W. BIRD

A chain of radar stations will soon roughly parallel the United States-Canadian border. The cluster of radomes pictured above are "somewhere in eastern Canada." It is the first unit in the multi-million dollar chain. ***(Photo courtesy of Bflo. Eve. News)***

IN recent years large, dome-shaped structures have appeared throughout the country, especially along the frontiers of North America. These mushroom-shaped buildings are "air-supported" radomes, as seen in Figure 1, which enclose and protect large, long-range radar antennas against high winds and the severe winter weather encountered in mountain areas or in the Arctic. If an enemy should send his jet bombers against us, these radar stations would play a vital role in our air defense network by detecting and warning of the attack. While they will withstand wind velocities up to 125 mph and temperatures ranging from —65° to 140°F, these enclosures cause practically no loss in transmission and reception of radar signals.

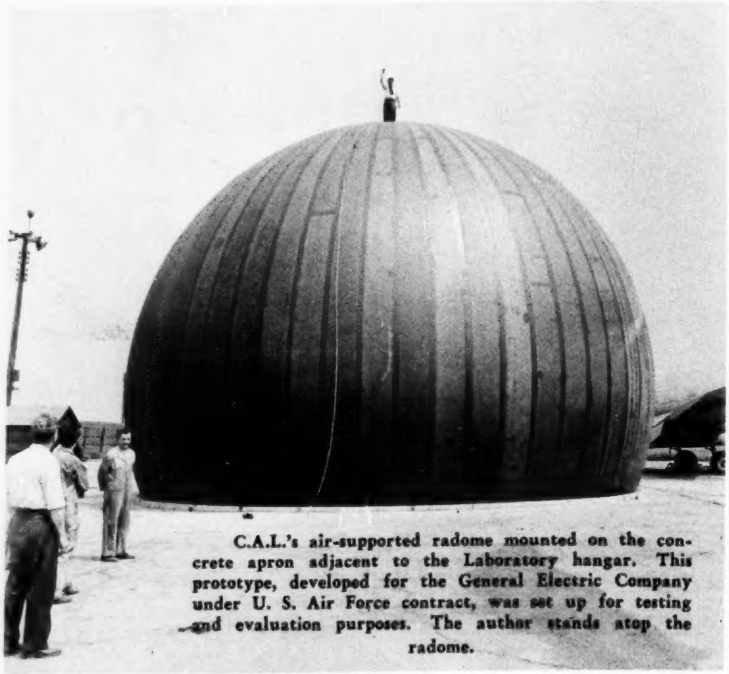
Although developed to meet a military need, the air-supported radome embodies many structural and architectural features which open new vistas in the design of portable or semi-permanent buildings. Constructed of a strong, thin, light-weight material, it is stiffened and stabilized solely by maintaining a small amount of air pressure within the unit. No interior supports or framework of any kind are necessary. The required air pressure is low enough so that commercial ventilation blowers can be used to support and ventilate the structure simultaneously. The light weight, portability and high structural efficiency of air-supported structures promise ready adaptation to the variety of military and commercial uses for which they are being considered.

TO MEET A NEW NEED

The Laboratory's research on the air-supported radome began in 1946 when the U. S. Government first started to develop the early-warning radar network which now surrounds the United States and the Arctic region. Extremely large antennas were required to provide the radar range needed for early warning of an approaching enemy air force. However, these antennas had to be protected against high winds and ice loads and, in order to obtain maximum radar transmission, protective enclosures had to be constructed from a thin, non-metallic material, having a low dielectric constant. Uniform thickness was necessary so that ribs or stiffners

would not distort the radar transmission pattern. Portability and light weight were also essential since the Air Force expected to transport these installations to remote areas by air.

This combination of requirements appeared nearly impossible to meet with any existing type of structure, and the Air Force sought a new method of enclosing the antenna. At a conference at the Watson Laboratories in 1946, the Laboratory proposed the development of a flexible, rubber-impregnated fabric enclosure held in position by air pressure. Despite considerable skepticism regarding the practicality of such a structure, the Laboratory was awarded a small contract to prove its feasibility by analysis and wind tunnel test.



C.A.L.'s air-supported radome mounted on the concrete apron adjacent to the Laboratory hangar. This prototype, developed for the General Electric Company under U. S. Air Force contract, was set up for testing and evaluation purposes. The author stands atop the radome.

PRELIMINARY DESIGN STUDIES

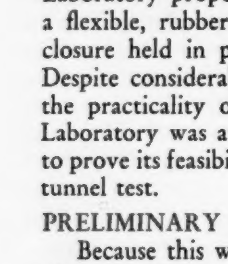
Because this was an entirely new type of structure, many problems had to be solved. In the past, use of air pressure to help support relatively flat roofs had been considered and several experimental projects had been tried with only limited success. However, the design of a suitable enclosure for the radar antenna required a structure approximately 36 feet high and 50 feet in diameter, with no internal or external supporting framework to interfere with transmission or reception of signals. The design involved, therefore, not only the problems of support, but also those of stability under wind loads and distribution of shear and tension loads in a flexible structure.

Early investigations revealed that surprisingly little useful information on aerodynamic loading (load resulting from airflow across a body's surface) was available. Although numerous wind tunnel tests had been made on basic spherical and cylindrical shapes, very small models had been used. Therefore, data provided by the tests did not apply to conditions that would be encountered with the extremely large radome. In addition, the degree of flexibility present in a radome limits the applicability of findings about pressure distributions on rigid spheres. In order to obtain information on stability and to supplement data on loading, a limited wind tunnel test program was undertaken, using a 1/24 scale model.

DEVELOPMENT OF FIRST PROTOTYPE

Wind tunnel tests and other preliminary studies showed the air-supported radome to be a stable, practical structure, even in areas where winds might rise well above 100 mph. The Laboratory was awarded a contract to develop a full-scale prototype unit for the General Electric Company, the Air Force contractor responsible for developing the complete early-warning radar installation. The first prototype was constructed of single-ply, neoprene-coated Fiberglas, weighing less than 2 pounds per square yard. It was spherical in shape, approximately 54 feet in diameter, 36 feet high, and was mounted on a 50-foot diameter base.

For test and evaluation, this radome was mounted on the concrete apron adjacent to the Laboratory hangar at the Buffalo airport. Note Figure 2. Passers-by speculated as to the nature of this curious object and Laboratory personnel were frequently asked when the "balloon" ascension would take place. During this initial trial period the unit was kept at an inflation pressure of less than one-tenth of a pound per square



THE COVER

The photo insert at left, also reproduced on the cover page, shows a molten stainless steel alloy being poured into shell molds for forming test bars. This operation is part of the Material Department's research and development of new stainless steel alloys that will withstand temperatures equalling those in the lower ranges of the cobalt-base and other superalloys. As aviation has advanced from subsonic to supersonic flight, the temperatures and stresses imposed on aircraft have increased. The high operating temperatures of modern power plants, coupled with the heat on aircraft structures which is generated by friction of air at high speed, weakens some materials to the point where the stresses imposed can no longer be borne. Conventional stainless steel alloys are considered suitable for temperatures up to about 1200°F. However, superalloys, which will bear temperatures up to about 1600°F, are being required for use in our latest high speed aircraft. These superalloys are both expensive and extremely scare. The metal pictured being poured represents one of three new modified stainless steel alloys C.A.L. has developed to replace the superalloys. These alloys have exhibited a two-fold gain in strength performance over standard stainless steels at 1500°F. Laboratory metallurgists are continuing to study the new alloys' load-carrying abilities at high temperatures, as well as their corrosion resistance and general metallurgical characteristics. It also is planned to proceed to the casting of jet blades for actual turbine engine trials.

inch. Despite this low pressure the walls were very rigid; few visitors could believe that they were constructed of a thin, flexible material that felt like drapery fabric.

MAJOR DESIGN PROBLEMS

Successful development of the air-supported radome required the solution of several major design problems. Aerodynamic loading is quite different on radomes than on conventional structures because of the radomes' smooth, spherical shapes. In addition to the normal wind pressure, high negative pressures (pulling out on the envelope instead of pushing it in) are developed which reach a maximum in a plane approximately 90° to the wind direction. These aerodynamic loads,

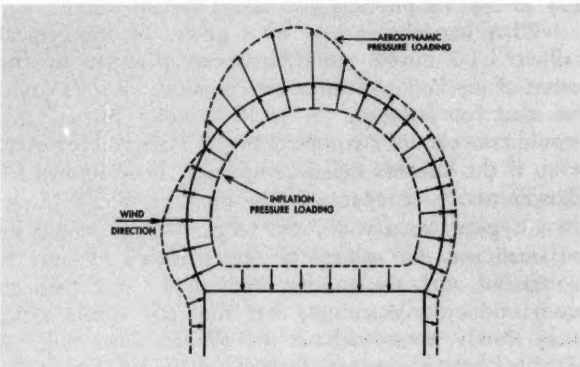


FIGURE 3 — A diagram of air loads acting on a radome.

together with the inflation pressure, result in a wide variation of the load acting on the surface of the radome. Figure 3 graphically shows this variation in load. The corresponding pressure loading required to provide necessary stability is included for comparison.

The amount of distortion in air-inflated structures depends on the shape, loading, materials used and general design. Excessive distortion of such structures will alter the aerodynamic loading because the new shape causes a change in airflow across the surface. This effect produces still further alteration in loads and may result in excessive stress concentrations. The spherical shape of the air-supported radome was chosen because spherical units can redistribute load with a minimum of distortion. In the design of units of other shapes, distortion and its effect on the stress distribution must be considered even more carefully.

Distribution of stress in an air-supported radome (load per unit area developed in the material) is shown in Figure 4. With the radome mounted on a tower, there is a general symmetry of loading about an axis approximately parallel to the wind direction. The stress in circular elements perpendicular to this axis varies from one element to the next, but is about equal at every point along a given element of the structure. However, as the aerodynamic loading is not uniform over the surface of the radome, the stress in the elements parallel to the wind direction varies from point to point.

Since the thin, flexible envelope material used in these radomes cannot redistribute load in bending,

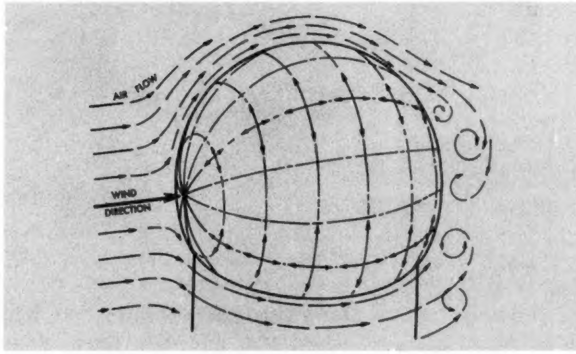


FIGURE 4 — A diagram of the stress distribution in a radome.

equilibrium conditions between the pressures acting on the surface and tension in the material will develop at every point on the surface. Externally applied loads, such as those at the base attachment resisting total drag, influence the distribution of stress in the entire envelope. Therefore, the loading conditions resulting in equilibrium of the unit as a whole must be properly considered in working out a favorable stress distribution. An important design problem is the introduction of restraining loads into the structure in such a manner as to satisfy these equilibrium conditions without developing local stress concentrations which would overload the material.

Use of suitable materials is a primary factor in the construction of air-supported radomes. The choice of materials was seriously limited at the time of the original development. A few high strength yarns had been developed but applications for structural fabrics were few and all available materials had serious limitations, such as poor flexibility, too much stretch, high water absorption and low wet strength, poor coating adhesion (which makes fabrication difficult), or poor weathering and sunlight resistance of the coating. The poor tear resistance of conventional fabrics proved to be a major difficulty. However, materials development programs were initiated and new fabrics and coatings are now commercially available to meet almost any requirement. C.A.L. has developed a two-ply material which can be punctured with an 8-inch spear while under full design load without further ripping. Synthetic yarns have been developed which, when used for coated fabrics, provide a strength-weight ratio equal to that provided by aluminum or structural steel. Many of these new materials have weathering and sunlight resistance much better than that normally associated with synthetic fibers. Maintenance problems are thereby greatly reduced.

A SUCCESSFUL MILITARY STRUCTURE

Air-supported radomes are now standard equipment on the majority of large ground radar installations throughout the United States and Canada. Radomes varying in size from 9 feet to over 50 feet in diameter are in successful operation. One 50-foot experimental radome rotates with the antenna at speeds up to 30 revolutions per minute. Among other potential military

applications under consideration are towers or masts that can be quickly erected or deflated and moved to new locations; portable hangars or shelters to protect personnel and equipment at remote or temporary bases; gas tight enclosures for protection of personnel and equipment in the event of bacteriological or radiological warfare. Several other new applications now under development are still classified for military reasons and cannot be revealed here.

HIGH COMMERCIAL PROMISE

Despite widespread military application, the air-supported structure's greatest potential appears to be for portable and semi-permanent structures in civil life. Some examples are: temporary or portable buildings for such applications as fair buildings, skating rinks, auditoriums, agricultural and industrial storage enclosures; as roofs over buildings requiring a wide expanse of uninterrupted floor area, such as auditoriums and warehouses or as roofs to enclose such areas as football stadiums during winter months. For storage areas the air-inflated structure offers an atmosphere that can be readily controlled, making it easy to maintain a given humidity or confine fumigating or preservative gases. Some of these commercial applications are illustrated in Figure 5.

To help visualize the practical possibilities of the air-supported structure, consider a moment the heavy trusses that support the roofs of auditoriums or sports arenas. These supports are needed to provide a high ceiling and large expanse of floor area uninterrupted by posts or columns. They could be completely eliminated with an air-supported roof. This type of roof would reduce loading on the walls and thus permit a further reduction in weight and cost of the structure. These economies in the form and construction of air-supported structures offer even small communities an opportunity to provide a large assembly hall or sports arena.

ARE AIR-SUPPORTED BUILDINGS PRACTICAL?

Because of the need for air locks or some other means of preventing excessive loss of air when entering or leaving air-supported buildings, the feasibility of handling large crowds in this type of structure has been frequently questioned. A simple air lock is used on the majority of air-supported structures today but it is not a necessary restriction. Revolving doors of a relatively simple design can be used to provide for continuous passage of people with a minimum loss of air. The air that is lost through the doors is easily replaced by the large volume, low pressure blowers which would be used both for ventilation and inflation of the structure, as mentioned earlier in this article.

Whether the higher pressure inside the building would cause discomfort to the occupants also has been questioned. A pressure difference of only a few ounces per square inch is required to support the roof of large structures. Inasmuch as this pressure difference is far below the pressure changes which occur in the normal atmosphere from day to day, no physical discomfort should result.

What happens in case of a power or mechanical failure? To insure maintenance of pressure in the event of mechanical failure, two or more blowers could be used for inflation. A small standby power unit would take care of a complete power failure. However, even if the blowers failed completely, little immediate danger to the occupants of the building would result. In a typical installation, the fabric weight would be so small and the volume of the enclosure so large as compared with the modest flow of air lost through door and other openings, that the roof would settle very slowly, even without the blowers operating. A lightweight cable system could be provided within the enclosure to prevent the roof cover from ever settling far enough to interfere with the movement of the people. An outstanding advantage of air-supported buildings is the complete absence of any heavy structure to collapse on the occupants in case of fire, earthquake, bombing or other emergencies.

WHAT ABOUT COST?

Although the unit cost of some newly developed fabrics is still high, the total cost of a typical air-supported structure is low compared with the cost of conventional type structures. Rough cost estimates prepared on a 110 by 225 foot athletic building with an air-supported roof were less than half of the estimated cost for a similar building having a conventional roof supported by steel trusses. In general, the unit cost of air-supported structures decreases with increasing size. This low cost, in combination with the structural efficiency, adaptability for portable or temporary structures and the smooth lines that lend themselves well to modern functional architectural design, portend a promising future for this radically new type of structure.

REPORTS

"DESIGN AND FABRICATION OF EXPERIMENTAL RADOME AND ASSOCIATED EQUIPMENT FOR VOLIR ANTENNA," Bird W.; under an Air Force contract; C.A.L. Report No. UB-747-D-19.

"DESIGN AND FABRICATION OF PROTOTYPE AN/CPS-6B AIR-SUPPORTED RADOME AND EQUIPMENT," Bird, W.; under an Air Force subcontract; C.A.L. Report No. UB-512J-1.

"WIND TUNNEL TESTS OF A 1/24 SCALE MODEL AIR-SUPPORTED RADOME AND TOWER," Kamrass, M.; under an Air Force contract; C.A.L. Report No. UB-909-D-1.

Why Tails Fail . . .

by **RICHARD K. KOEGLER**

In the late 1930's and the early years of World War II, a great many airplanes were designed, test flown and put into production. Suddenly many cases of tail failure were reported where pilots performing high speed dives experienced "frozen" or "loose" elevator controls. Sometimes the airplanes, upon entering or recovering from dives, tended to nose up or down. The P-38 Lightning and the P-47 Thunderbolt fighters were among the first to encounter these difficulties. Eventually almost every experimental fighter design encountered them. Subsequent research on tail loading vastly improved the situation but not before numerous tail failures, crashes, and fatalities had resulted.

Loads on tail surfaces have always been difficult to calculate. Tails are relatively small compared with wings, yet they must balance the unstable characteristics of wings. Comparatively small changes in airload on the aircraft's wings will drastically affect the load on the tail. Aircraft designers, consequently, must have specific data on the aerodynamic characteristics of both wings and tails. They must know which of the infinite number of possible flight conditions and maneuvers the airplane can perform safely and they must select from these the ones likely to result in the most severe tail loadings.

COMPRESSIBILITY EFFECTS

About fifteen years ago, designers were suddenly confronted with aircraft performance that exceeded existing knowledge on tail loading. What had happened was this: maximum airplane flight speeds and altitudes had increased to a point where "compressibility effects" became important in dive tests. As air passes around the outside of an airplane or other aerodynamic shape, it follows flow patterns which develop air pressure on the body and produce lift forces of airfoils. Because of these pressure distributions, the airfoil and body tend to pitch up or down, depending on the shape. Each aircraft design is so made that pitching produced by airflow over the horizontal tail properly balances out other pitching influences. However, the distributions of these forces change seriously as speed increases beyond the 400 mph region. These changes result from the behavior of air when density changes due to pressure differences become significant. These rather large changes in force distribution at higher airspeeds are known as "compressibility effects."

When the speed of air at some region on the airfoil reaches the speed of sound (760 mph at sea level) even more drastic changes in pressure distribution are encountered. These often occurred on early World War II aircraft when speeds reached Mach .75 (75% of the speed of sound).

These effects of compressibility and of Mach number were dependent on the shapes of wings, fuselages and tails. Their computation was extremely complex and not very well understood. They caused airplanes of some designs to nose downward as speed increased at high airspeeds. Large elevator deflections and very high stick forces were then required to overcome downward tendencies and to effect a pullout. Sometimes, when speed decreased rapidly during the pullout, the downward tendencies would suddenly disappear and the airplane would nose up. On other designs, however, these effects were such that, as speed increased, the airplane was prone to nose up. In some instances the elevator became ineffective. Due to the resulting confusion it was years before the causes of the trouble were found and the needed data obtained.

PULLUP MANEUVERS

About the time Mach number effects were beginning to be understood and the situation brought under control by experiments in wind tunnels that had speed capabilities equal to the diving speeds of aircraft under design, another emergency arose: determination of tail loads in pullup maneuvers. Previously, empirical formulae for determining tail loads had been devised on the basis of carefully made tests on aircraft of about 1927 vintage and incorporated in tail load specifications. These formulae had not been based on the aircraft's stability characteristics. It was assumed that other criteria, such as those for the tail load required for equilibrium at various speeds and load factors, would account for any unusual static stability characteristics.

The empirical formulae indicated large down loads on the tail and the up loads were computed as one half of the down loads. Following a series of upward failures in pullup maneuvers, the U. S. Air Force and NACA made investigations based on dynamic stability and control technology. That is, in these investigations, the dynamic motions of the aircraft were determined throughout complete maneuvers, in contrast to previous work wherein solutions were obtained only for

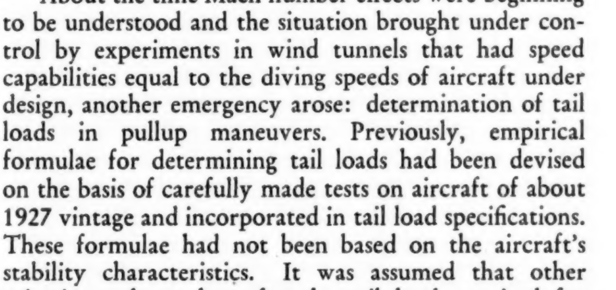


FIGURE I — The typical motion of the elevator in a pullup and the resulting tail load and airplane load factor.

FIGURE 2 — The F-80A airplane used in C.A.L.'s structural tail load research.

certain simplified cases such as steady pullups or instantaneous control motions. These investigations revealed that, on airplanes with low stability, very heavy up loads on the tail resulted from stick motions used to initiate the pullup. See Figure 1. The technique was to overcontrol initially in order to obtain a rapid buildup of load factor and then momentarily reverse control to arrest the load factor buildup at the desired point.

This newly uncovered method of calculating tail loads for the specified maneuver was carefully investigated during World War II and thereafter in studies and flight tests by NACA and the U. S. Air Force. Cornell Aeronautical Laboratory's contribution to the solution of the tail load problem began later with a U. S. Air Force-sponsored dynamic stability and tail loads flight test program on the F-80A airplane. The airplane in flight is pictured in Figure 2. In this program, another proof of the method's accuracy was obtained, this time employing the more recent high performance F-80A airplane. This program also provided, for the first time, flight confirmation of certain dynamic stability coefficients which were needed for computations but which had never before been directly corroborated by flight tests.

BUFFETING — ANOTHER PROBLEM

Horizontal tail failures also have been found, in many cases, to be caused by tail shake or "buffeting" when the turbulent wake from the wing impinges on the tail surfaces. This unpleasant condition is only arbitrarily covered presently in design specifications and is so complex that efforts to design for it with the present state of knowledge would probably be fruitless. However, recent C.A.L. flight tests for the U. S. Air Force showed that no likely elevator control motion or customary flight condition could produce loads sufficient to cause the failures that were known to occur in flight on the airplane under investigation. But the tests did reveal that the buffeting associated with stalling at moderately high speeds could produce such loads. In addition, flight test data on the buffeting in pullups of certain experimental versions of World War II aircraft showed that load fluctuations were encountered which were within the static strength boundaries of their tail surfaces, but could cause fatigue failures in about one hundred such maneuvers.* Designers now arrange the location of the wing and tail in such a way that wing wake impinges on the tail in as little of the range of the aircraft's useable flight conditions as is possible. Wing wake is checked in the wind tunnel. Flight tests are then made to determine actual buffet boundaries, note Figure 3, and the airplane is placarded accordingly to instruct the pilot to avoid flight conditions under which buffeting would be severe. The determination of the safe distance the buffet boundary can be penetrated is based on trial and error flight testing, aided as much as possible by instrumentation for accurately determining flight conditions.

*"The Structural Tail Load Problem — Theory, Tests and Criteria," R. K. Koegler, C.A.L. Report No. 49, January 1953.

VERTICAL TAIL LOADS

The latest source of trouble with tail loads has been in connection with vertical tail surfaces. These present a more tenuous problem in the promulgation of design load criteria than horizontal tail surfaces do. In the case of the horizontal tail, maneuvers likely to cause large tail loads usually are symmetrical pullups which produce high load factors and are frequently associated with high stick forces. These clues assist the pilot to some degree in avoiding unsafe horizontal tail loads. However, high loads on vertical tails are not always associated with high side accelerations or rudder control pedal forces. The fuselage side area and shape are such that even with relatively large sideslip angles it is not possible to develop as much sideways airforce as the wing can develop in a vertical direction. On some designs it is quite easy to deliberately move the rudder to produce loads which will cause the vertical tail to break off without subjecting the pilot to excessive side accelerations. In fact, a number of cases have been recorded where aircraft have returned from directional stability tests with partially failed vertical tails. Yet these same aircraft have been found to be perfectly safe in normal operation because such rudder motions are never used. Thus, the flight needs for rudder motions are far from being understood. NACA is currently pursuing a major effort to obtain records of maneuvers actually performed in operations which load the vertical tail. At C.A.L. a simple airborne recorder has been investigated for the Air Force which might be carried even in combat operations to obtain data on the vertical tail loads imposed during an aircraft's

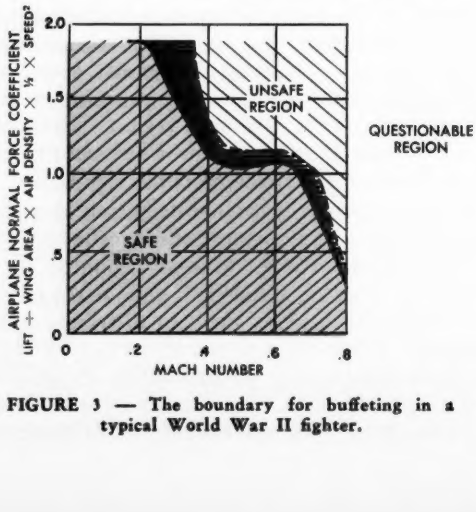


FIGURE 3 — The boundary for buffeting in a typical World War II fighter.

maneuvers. Once sufficient data are available, an effort to correlate them with airplane lateral stability and control characteristics may produce a more rational understanding of this problem.

THE ROLLING PULLOUT

High loads on vertical tail surfaces are also encountered in another maneuver in which the rudder is not moved at all. In World War II, failures in the vertical tails of one type of fighter were found to occur sometimes at quite moderate airspeeds when ailerons were moved to initiate a rolling motion during the airplane's performance of a high "g" pullup. Subsequent study by NACA showed that, under these flight conditions, deflection of the ailerons applied very large aerodynamic forces tending to make the airplane turn. It turned so far under the action of these forces that the sideways component of the airspeed was sufficient to fail the vertical tail. The NACA study showed how to calculate loads for this airplane and how to effect cures for the trouble. It called this maneuver "the rolling pullout." Once this maneuver had been disclosed as potentially critical, efforts were made to apply the same calculation procedures to other types of aircraft. Subsequent studies by NACA and others showed that improvements in these calculation procedures were required for application to other aircraft. In fact, as airplane designs progressed toward configurations which could fly at transonic and supersonic speeds, each successive change seemingly made it necessary to use a more complex set of equations.

At this point the U. S. Air Force requested C.A.L. to write out the most complete set of equations it could envision and then solve these equations for the F-80A, first in their complete form and then in a series of successive simplifications. When their simplest acceptable form had been determined, the equations were set up on analog computers. The methods were confirmed by comparing the rolling pullout motions and tail loads actually measured by C.A.L. on an F-80A airplane with those calculated by this method. Recent trends in airplane designs have made rolling pullout maneuvers even more critical than before. At present a great deal of work is underway at C.A.L., NACA and various airplane companies in efforts to improve airplane behavior in such maneuvers. In most of this work the equations being used are similar to those found to be the minimum acceptable ones in C.A.L.'s studies for the U. S. Air Force.

What the future will be like in respect to the tail load problem is, of course, impossible to know. As designs progress, there will probably always be some surprises, but research and development, kept a pace ahead of actual design practice, will not only help to limit them, but will point to their early solution.

REPORTS

Editor's Note: The Laboratory has issued numerous reports describing research done for the U. S. Air Force on horizontal and vertical tail loads including calculations and measurements during symmetrical pullups, rolling pullouts and rudder kick maneuvers on the F-80A airplane. The list is too lengthy to be published here, but is available upon request to the Editor.

About the Authors...

WALTER W. BIRD'S enthusiasm for the development of air-supported structures began eight years ago. At that time he was assigned the task of proving the feasibility and developing a practical design of an air-supported radome to house radar antenna. He has been associated with all phases of the Laboratory research on radomes and other air-supported structures, including development of new materials and equipment associated with their use. Mr. Bird has designed radomes which vary in size from 9 feet to over 50 feet in diameter and has acted as a design consultant to the Canadian government for radome installations. He has originated the design of a number of other types of air-supported structures both for government and industry.

Mr. Bird started his professional career with the Pullman Standard Car Manufacturing Company in Chicago where he helped design the new streamlined trains introduced in the middle thirties. In 1939 he affiliated with the Curtiss-Wright Airplane Division in Buffalo, N. Y. as a stress engineer and advanced to project stress engineer, head of the production stress section and head of the engineering laboratories.

When World War II ended, he transferred to the Curtiss-Wright Research Laboratory which, in January 1946, became the Cornell Aeronautical Laboratory. In May 1946 he was assigned to C.A.L.'s newly formed Development Division. At that time he started his work on air-supported structures. He is presently assistant head of the Industrial Division, the Laboratory's newest department, and continues to direct the Laboratory effort in radomes and other air-supported structures.

Mr. Bird received his B.S. degree in aeronautical engineering from M.I.T. in 1934. He returned to that school for a year's graduate work in business and engineering administration under the Sloan Foundation in 1936. He is a member of the Institute of The Aeronautical Sciences, the Professional Engineering Society, and Sigma Xi, honorary engineering society.

RICHARD K. KOEGLER'S keen interest in the problems of aircraft tail load determination did not come about by accident. Although his background as a stress analyst prompted an interest in the field, a great incentive for further study was vividly established the day before a precarious dive demonstration. At that time the inadequacy of tail load design requirements was just becoming recognized. The pilot who was to perform the maneuver asked Mr. Koegler for assurance that the tail was strong enough. Mr. Koegler could honestly answer that the tail was strong enough to support the design load; he could not reply with certainty that the design load was as great as the load the pilot might apply. Although the maneuver was successful, the incident made a lasting impression on the author.

Mr. Koegler's professional experience began with the Consolidated Aircraft Corporation in 1936 as a stress analyst. He joined the Curtiss-Wright Airplane Division in Buffalo in 1938, eventually becoming chief of the structures section. During that time he worked on such airplanes as the P-36, P-37, P-40, P-46, P-60 and the XF15C-1. Between 1945 and 1947 he was project engineer for the H-12 helicopter at the Bell Aircraft Corporation.

Mr. Koegler joined C.A.L. in 1947 as a principal engineer in the Flight Research Department. He is presently head of the aeronautical engineering branch of that department. He has headed the study of the structural tail load problem and has been actively engaged in virtually all stability and control research carried out by the department.

He graduated from M.I.T. in 1936 with a B.S. degree in aeronautical engineering. He has completed graduate work at both M.I.T. and the University of Buffalo. Mr. Koegler has contributed to meetings of the Advisory Group for Aeronautical Research and Development of NATO and is a member of the Institute of The Aeronautical Sciences, Society of Automotive Engineers, and Society for Experimental Stress Analysis.

Recent C. A. L. PUBLICATIONS

Requests for copies of the following unclassified reports should be directed to the Editor

"A COMPARISON OF THE DIRECT MEASUREMENT OF THE SIDESLIP ANGLE WITH THE MEASUREMENT OF THE SIDESLIP ANGLE BY INTEGRATION OF THE SIDE FORCE EQUATION," Newell, F. D.; C.A.L. Report No. FRM 212; 5 pages (July 1954).

A description is given of an investigation for the F-80A airplane which determined that sideslip angle as found by the integration of the side force equation does not agree with sideslip angle obtained by a direct measurement.

"A GUIDE MANUAL OF COOLING METHODS FOR ELECTRONIC EQUIPMENT," Welsh, J. P.; Bureau of Ships Contract No. NObsr-49228; C.A.L. Report HF-710-D-16; 199 pages (April 1954).

Principles and techniques are enumerated for the design of electronic parts, subassemblies and equipments which allow maximum achievement of heat transfer and miniaturization.

"A THEORY OF SHOCK WAVE BOUNDARY LAYER INTERACTION," Goodman, T. R.; thesis presented to Faculty of Graduate School of Cornell University; C.A.L. Report No. 61; 41 pages (June 1953).

In this paper, the author considers the problem of a linearized shock wave — a Mach wave — impinging on a laminar boundary layer along a flat plate.

"CONSTRUCTION OF ARC MELTING FURNACE FOR TITANIUM AND ZIRCONIUM," Gillig, F. J.; C.A.L. Report No. 512-221-1; 11 pages (Sept. 1954).

A description of an arc furnace capable of liquifying high melting point reactive metals and alloys in an inert atmosphere is provided.

"DEVELOPMENT OF EQUIPMENT FOR THE EXPERIMENTAL MEASUREMENT OF THE MOMENTS OF INERTIA AND PRODUCT OF INERTIA OF AIRCRAFT," Woodard, C. R.; C.A.L. Report TB-822-F-3; 38 pages (June 1954).

A discussion of the design evolution, present design, calibration and shakedown of test equipment for the experimental measurement, by the spring oscillation method, of the moments of inertia and product of inertia of airplanes.

"FLIGHT TEST INVESTIGATION OF TURBULENCE SPECTRA AT LOW ALTITUDE USING A DIRECT METHOD FOR MEASURING GUST VELOCITIES," Notess, C. B. and Eakin, G. J.; C.A.L. Report VC-839-F-1; 55 pages (July 1954).

A method was developed for measuring the character of atmospheric turbulence using an airplane as a probe. Time (or space) histories of the components of atmospheric turbulence were directly computed from the recorded data.

"INSTRUMENTATION AND TECHNIQUES FOR CONDUCTING BEARING AND SHEAR TESTS AT ELEVATED TEMPERATURES," Yerkovich, L. A.; Guarnieri, G. J.; Vawter, F. J.; address to First International Instrument Congress and Exposition of Instrument Society of America; 4 pages (Sept. 1954).

This paper describes the equipment and instrumentation developed for an investigation of the high-temperature bearing and shear creep properties of several aircraft sheet and rivet alloys.

"INVESTIGATION OF THE COMPRESSIVE, BEARING AND SHEAR CREEP-RUPTURE PROPERTIES OF AIRCRAFT STRUCTURAL METALS AND JOINTS AT ELEVATED TEMPERATURES," Vawter, F. J.; Guarnieri, G. J.; Yerkovich, L. A. and Derrick, G.; WADC-TR 54-270, Part I (C.A.L. Report KB-831-M-9); 85 pages (June 1954).

Conventional tensile creep data of several aircraft structural alloys are supplemented with data on compression, bearing and shear properties. Description of equipment and fixtures for conducting tests is included.

"LOW FREQUENCY DIFFERENTIATOR," Gillen, R. G. and Malone, D. P.; C.A.L. Report No. FRM 214; 8 pages (August 1954).

This is a description of a relatively simple, non-mechanical low frequency differentiator needed in various work phases encountered in C.A.L.'s Flight Research Department.

"ON THE APPLICATION OF THE METHOD OF CHARACTERISTICS TO THE STUDY OF IRROTATIONAL THREE-DIMENSIONAL SUPERSONIC FLOW," Ferrari, C.; C.A.L. Report No. 53; 28 pages (May 1953).

A procedure for computing the velocity field in three-dimensional supersonic flow, developed in 1936 by the author, is compared with procedures recently advanced for handling the problem.

"STUDY OF FIRE EMERGENCY CONTROL SYSTEM," Naulty, H. W.; C.A.L. Report V-827-D-3; 52 pages (June 1954).

The study and development of a fire emergency control system for multi-engine aircraft is described.

"SUPERSONIC LATERAL DERIVATIVE STUDY, PART II, DERIVATIVES DUE TO RATE OF YAW AND RATE OF SIDESLIP," Goodman, T. R.; WADC TR 54-610, Part II (C.A.L. Report No. TB-541-F-10); 33 pages (Dec. 1954).

This paper deals with the yawing or sideslipping wing. Two linear combinations of rolling and sideslipping are considered.

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